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DRUG DISCRIMINATION UNDER TWO CONCURRENT FIXED-INTERVAL FIXED-INTERVAL SCHEDULES

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Pigeons were trained to discriminate 5.0 mg/kg pentobarbital from saline under a two-key concurrent fixed-interval (FI) 100-s FI 200-s schedule of food presentation, and later under a concurrent FI 40-s FI 80-s schedule, in which the FI component with the shorter time requirement reinforced responding on one key after drug administration (pentobarbital-biased key) and on the other key after saline administration (saline-biased key). After responding stabilized under the concurrent FI 100-s FI 200-s schedule, pigeons earned an average of 66% (after pentobarbital) to 68% (after saline) of their reinforcers for responding under the FI 100-s component of the concurrent schedule. These birds made an average of 70% of their responses on both the pentobarbital-biased key after the training dose of pentobarbital and the saline-biased key after saline. After responding stabilized under the concurrent FI 40-s FI 80-s schedule, pigeons earned an average of 67% of their reinforcers for responding under the FI 40 component after both saline and the training dose of pentobarbital. These birds made an average of 75% of their responses on the pentobarbital-biased key after the training dose of pentobarbital, but only 55% of their responses on the saline-biased key after saline. In test sessions preceded by doses of pentobarbital, chlordiazepoxide, ethanol, phencyclidine, or methamphetamine, the dose–response curves were similar under these two concurrent schedules. Pentobarbital, chlordiazepoxide, and ethanol produced dose-dependent increases in responding on the pentobarbital-biased key as the doses increased. For some birds, at the highest doses of these drugs, the dose–response curve turned over. Increasing doses of phencyclidine produced increased responding on the pentobarbital-biased key in some, but not all, birds. After methamphetamine, responding was largely confined to the saline-biased key. These data show that pigeons can perform drug discriminations under concurrent schedules in which the reinforcement frequency under the schedule components differs only by a factor of two, and that when other drugs are substituted for the training drugs they produce dose–response curves similar to the curves produced by these drugs under other concurrent interval schedules.

Key words: drug discrimination, concurrent fixed-interval schedules, pentobarbital, chlordiazepoxide, ethanol, phencyclidine, methamphetamine, key peck, pigeons

In drug-discrimination experiments, the schedule of reinforcement is a major determinant of the shape of the dose–response curve when other doses of the training drug, or doses of other drugs, are substituted for the training drug. When responding is maintained by fixed-ratio (FR) schedules, dose–response curves usually are quantal in individual animals; that is, almost all responses occur on one key after each dose. However, when responding is maintained by interval schedules, dose–response curves are usually are graded; that is, responses are distributed on both keys after some drug doses.

These findings are consistent with data from simple FR and simple fixed-interval (FI) schedules (Massey, McMillan, & Wessinger, 1992), both FI and FR components of multiple schedules (Snodgrass & McMillan, 1991; McMillan & Hardwick, 1996), concurrent FR FR schedules (McMillan & Li, 1999a), concurrent FI FI schedules (McMillan, Li, & Hardwick, 1997), and concurrent variable-interval (VI) VI schedules (Snodgrass & McMillan, 1996). Although most of these experiments were conducted using pigeons, some of these findings have been replicated with rats (McMillan & Hardwick, 2000). In most of the experiments, pentobarbital has served as the training drug, but these effects have been produced with other training drugs (Massey et al., 1992; McMillan, Cole-Fullenwider, Hardwick, & Wenger, 1982).

As it is usually conducted, the drug-discrimination procedure is a conditional discrimination with both response choices available concurrently (if drug has been administered respond on Operandum A, if no drug has been administered respond on Operandum B). Snodgrass and McMillan (1991) suggest-

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ed that the schedule of reinforcement in drug-discrimination experiments might have characteristics of a concurrent schedule under some conditions. For example, at doses of the training drug different from those administered before training sessions, the presence or absence of the training drug may be difficult to discriminate. Under such conditions, the schedule may become analogous to a concurrent schedule because the drug stimulus does not signal reliably which response alternative will produce the reinforcer. This observation led to a series of experiments to study drug discrimination under concurrent reinforcement schedules. In these experiments, quantal dose–response curves in individual animals have been produced under concurrent FR FR schedules (McMillan & Li, 1999a), and graded dose–response curves have been produced under concurrent FI FI schedules (McMillan & Li, 1999b; McMillan et al., 1997) and under concurrent VI VI schedules (Snodgrass & McMillan, 1996), as predicted by the generalized matching law (Baum, 1979).

In experiments on drug discrimination under concurrent FI FI schedules, pigeons were trained to discriminate 5.0 mg/kg pentobarbital from saline under a concurrent FI 240-s FI 60-s schedule of food presentation (McMillan et al., 1997). Drug discrimination was established under this schedule, although there was some degree of undermatching (proportionally more responses occurred on the key on which responses were reinforced under the FI 240-s schedule than would be predicted by perfect matching of the proportion of responses made on that key to the proportion of reinforcers delivered for responding on that key) after saline training sessions. Analysis of cumulative response records showed that responding on the key programmed under the FI 60-s component of the concurrent schedule was characterized by a pause followed by a short acceleration of responding to a terminal rate to produce the reinforcer, whereas responding on the key programmed under the FI 240-s component of the schedule was characterized by short high-rate bursts of responding during the postreinforcement pauses on the other key. When other drugs were substituted for pentobarbital and the birds were tested under a concurrent FI 150-s FI 150-s schedule of food presentation, graded dose–response curves were generated for pentobarbital, chlordiazepoxide, ethanol, and phencyclidine, with increasing doses of each of these drugs producing increased responding on the pentobarbital-biased key with two exceptions. First, for some birds the pentobarbital dose–effect curve turned over and began to descend after high doses of pentobarbital; second, the phencyclidine dose–response curve did not reach the same high level of responding on the pentobarbital-biased key as did the other drugs. In contrast, after methamphetamine the dose–response curve was flat, with most responses occurring on the saline-biased key.

Although McMillan et al. (1997) produced the predicted graded dose–response curves in drug-substitution experiments, it was possible that the obtained effects depended on the actual schedule values used in these experiments. In a follow-up study (McMillan & Li, 1999b), drug discrimination was established in two groups of pigeons under a concurrent FI 15-s FI 285-s schedule. One group of pigeons were the same birds used by McMillan et al. (1997), and therefore they had a history of responding under the concurrent FI 60-s FI 240-s schedule, whereas the other group of birds was trained only under the concurrent FI 15-s FI 285-s schedule. The concurrent FI 15-s FI 285-s schedule was chosen because Davison and Jones (1995) suggested that the generalized matching law is a poor discriptor of extreme choice, which they defined as a concurrent schedule on which 90% or more of the reinforcers were produced by responding on one of the two response alternatives. Indeed, under conditions in which 80% of the reinforcers were produced by responses on one of the two response alternatives, matching behavior has been obtained under concurrent FI FI schedules (Shimp, 1971). In the experiments by McMillan and Li (1999b), when responding stablized under the concurrent FI 15-s FI 285-s schedule, pigeons in both groups made 75% to 85% of their responses on the key on which responding was reinforced under the FI 15-s component of the schedule (undermatching); however, when the schedule was changed to a concurrent FI 150-s FI 150-s schedule for drug-substitution experiments, the presence or absence of pentobarbital con-

tinued to control the pattern of responding of the birds with the extensive training history, but the responding of the birds without this history came under control of the changed reinforcement schedule rapidly so that responding occurred almost equally often on the two response keys during these sessions. Under the concurrent FI 150-s FI 150-s schedule, the dose–response curves based on data from the entire session were flat. However, if data were used only from the first minute of the test sessions under concurrent FI 150 s FI 150 s before the schedule change assumed control of the behavior, dose–response curves for pentobarbital were graded for both the pigeons with previous experience under the concurrent FI 60-s FI 240-s schedule and the birds without this history. Thus, even after training under extreme values of the concurrent FI 15-s FI 285-s schedule and under conditions in which schedule changes disrupted stimulus control by the training drug under a concurrent FI 150-s FI 150-s schedule, the concurrent FI FI schedules continued to generate the graded dose–response curves predicted by the matching law.

In the current experiments, we extended the generality of our findings to concurrent-schedule values in which the durations of the component FI schedules were less different from each other: concurrent FI 40 s FI 80 s and FI 100 s FI 200 s. Both of these schedules maintain the same 2:1 ratio of reinforcer availability under the two components of the concurrent schedule, but the absolute schedule values differed. These characteristics permitted determination of whether drug discrimination could be established when there was only a 2:1 ratio of reinforcer availability under the shorter interval component compared to the longer interval component. These schedule characteristics also allowed determination of whether absolute durations of the concurrent FI FI schedule values produced differences in response patterns when the ratio of reinforcers programmed for delivery under the component FI schedules was constant. In previous experiments, it has been shown that pigeons can discriminate differences in reinforcer ratios even smaller than 2:1 under concurrent FI FI schedules (White & Davison, 1973); however, these experiments did not involve drug discrimination.

Pentobarbital was selected as the training drug for these experiments so that the results could be compared directly to our previous experiments in which pentobarbital was established as the discriminative stimulus under concurrent schedules (McMillan & Hardwick, 2000; McMillan & Li, 1999b; McMillan et al., 1997; Snodgrass & McMillan, 1996). Chlordiazepoxide and ethanol were substituted for pentobarbital in generalization tests because these drugs have been reported to substitute as discriminative stimuli for pentobarbital in drug-discrimination studies (Colpaert, Desmedt, & Janssen, 1976). Methamphetamine was chosen because it has not substituted for pentobarbital as a discriminative stimulus, and phencyclidine was chosen because it has substituted partially for pentobarbital in drug-discrimination tests (McMillan & Hardwick, 1996).

METHOD

Subjects

Five adult male White Carneau pigeons (Palmetto Pigeon Plant) were used in these experiments. Birds P257, P259, and P260 had been used in previous experiments. Bird P347 was added to this group for all experiments. Birds P347 and P380 were experimentally naive. When Bird P259 died, Bird P380 was added for the concurrent FI 40-s FI 80-s schedule. The pigeons were individually housed with free access to food and water in a temperature- and humidity-controlled room that was maintained under a 12:12 hr light/dark cycle. After 100% body weights were determined over a 2-week period, the pigeons were reduced to, and maintained at, approximately 80% of these weights for the duration of the study. Supplemental food was provided after experimental sessions as necessary to maintain the 80% body weights (range, 421 to 515 g).

Apparatus

The experimental chamber was a Gerbrands Model G5610-A pigeon test cage enclosed in a Gerbrands Model G7211 sound- and light-attenuating cubicle. Two 28-V DC lights illuminated the experimental chamber during the session except during a food cycle

when a light over the food hopper was illuminated. On the front panel of the cage, three Gerbrands response keys (Model G7311) were mounted 7 cm apart, 20 cm above the grid floor. The center key was not used in these experiments and was dark at all times. When operative, the left key was blue and the right key was yellow. The opening to a Gerbrands food hopper, which allowed access to mixed grain, was centered between the response keys at floor level. A Gateway microcomputer, located in a room adjacent to the room containing the experimental chamber, controlled the reinforcement schedule and recorded the data through a MED Associates interface.

Procedure

The training of Birds P257, P259, and P260 has been described by McMillan et al. (1997). The 2 experimentally naive pigeons were trained using similar procedures. Briefly, the pigeons were trained to peck the blue left response key and the yellow right response key by an autoshaping procedure. After responding had been established on both keys, the FI schedules were introduced. In the present experiments, 5.0 mg/kg pentobarbital served as the training drug. Experiments were conducted under the concurrent FI 100-s FI 200-s schedule first. Following an intramuscular injection of 5.0 mg/kg pentobarbital or saline, birds were placed in the test chamber and a 10-min presession period followed. During this 10 min, the chamber lights were extinguished and key pecks were not recorded. At the end of the presession period, the houselights and keylights were illuminated and the schedule contingencies were initiated. During these discrimination training sessions, both the left and right keys were transilluminated, and a different and independent FI schedule was operative on each key. Completion of either of the FI components resulted in delivery of the reinforcer (4-s access to mixed grain). After administration of the training drug, the FI 100-s component was programmed on one key and the FI 200-s component was programmed on the other. The key associated with each schedule component was counterbalanced across birds. After saline administration the schedules for the two keys were reversed. Training sessions lasted 40 min. Responding was maintained under this concurrent FI FI schedule throughout the first study with the exception of control and test sessions, which will be described later.

To prevent immediate reinforcement of switching between keys (Catania, 1966), a changeover delay (COD) of 3 s was imposed, such that a response could not produce a reinforcer unless it occurred at least 3 s after the bird switched from responding on one key to responding on the other key. Training sessions were conducted 6 days per week. During these training sessions pentobarbital and saline administration alternated.

Test sessions were interspersed with training sessions when the performance was stable. During these test sessions, conducted on Tuesdays and Fridays, other doses of pentobarbital and other doses of other drugs were administered, instead of saline or the training dose of pentobarbital. Training sessions continued on the other 4 days. The procedure during test sessions was similar to that during training sessions, except that during test sessions a concurrent FI 150-s FI 150-s schedule of reinforcement was in effect in an attempt to prevent the training schedule from controlling the pattern of responding on the two keys. This FI value was chosen because it is intermediate between the FI 100-s and the FI 200-s schedule values used during the training sessions. In addition to the other doses of pentobarbital and other drugs that were administered during test sessions, saline and the pentobarbital training dose were administered during sessions under the concurrent FI 150-s FI 150-s schedule prior to and after the determination of each dose–response curve. These test sessions were intended to measure the effect of the schedule change on the stability of the stimulus control of behavior by saline and by the training dose of pentobarbital when the schedule was changed to that used during test sessions. Drug-substitution tests were conducted in single test sessions on different days, with single observations of each dose level conducted in each subject. All dose levels for a single drug were administered in a randomized order before exposure to a different drug. The order of drug testing was pentobarbital, phencyclidine, methamphetamine, ethanol, and chlordiazepoxide. The test sessions also lasted 40 min.

On completion of these manipulations, the schedule was changed to a concurrent FI 40 s FI 80 s for Birds P257, P260, and P347. P380 was trained to key peck as noted previously and then was placed on the concurrent FI 40-s FI 80-s schedule. Next, the drug manipulations described above with the concurrent FI 100-s FI 200-s schedules were repeated in the same order. During the drug-substitution tests in this part of the experiment, a concurrent FI 60-s FI 60-s schedule was in effect.

The number of CODs, the number of responses on each key, the time spent responding under each FI component and the number of reinforcers earned under each schedule component were recorded. Other measures were derived from these data. One such measure was the percentage of responses on the pentobarbital-biased key. The pentobarbital-biased key was defined as the key associated with the shorter FI component of the concurrent schedule (FI 100 s under the concurrent FI 100-s FI 200-s schedule and FI 40 s under the concurrent FI 40-s FI 80-s schedule) after the administration of pentobarbital during the training sessions. The saline-biased key was defined in the same manner as the key associated with the shorter FI component after administration of saline during the training sessions. The percentage of responses on the pentobarbital-biased key was derived by dividing the number of responses emitted on the pentobarbital-biased key by the sum of responses emitted on both keys and converting the proportion to a percentage. A second derived measure was the percentage of time allocated to responding on the pentobarbital-biased key. A response on the pentobarbital-biased key began recording the accumulation of time until a response on the saline-biased key switched the recording of the accumulation of time to the other key. The total time accumulated after responses on the pentobarbital-biased key was divided by the accumulated time spent responding on both keys to calculate the percentage of time spent responding on the pentobarbital-biased key. The total number of responses on a key was divided by the time spent responding on that key to calculate the rate of responding on the pentobarbital-biased key and the saline-biased key. The sum of the number of responses on the two keys was divided by the total time spent responding on the two keys to calculate the overall rate of responding.

Pentobarbital sodium (Sigma) at doses of 1.0 to 13.0 mg/kg, phencyclidine hydrochloride (PCP, National Institute on Drug Abuse) at doses of 0.1 to 1.8 mg/kg, methamphetamine hydrochloride (Sigma) at doses of 0.3 to 3.0 mg/kg, chlordiazepoxide hydrochloride (Hoffman-La Roche) at doses of 0.3 to 10.0 mg/kg, and ethanol at doses of 0.3 to 3.0 g/kg were studied. All drugs except ethanol were dissolved in 0.9% physiological saline to a concentration allowing an injection volume of 1 ml/kg and were administered intramuscularly into a breast muscle. Physiological saline was used for vehicle control injections. Doses are expressed as the salt forms of the drugs, except for ethanol. All drugs were administered 10 min before the session. The pigeons were placed in the test chamber during the 10-min presession period. Ethanol (100% w/v) was diluted to a 10% w/v solution with tap water. The 10% ethanol solution or tap water, which was used as the vehicle control, was administered 15 min prior to session initiation through a rubber tube that passed down the esophagus into the proventriculus.

RESULTS

Table 1 shows, for each bird under the FI 100-s component of the concurrent FI 100-s FI 200-s schedule, the mean number of reinforcers delivered, the mean number of responses made, and the mean time allotted to responding during the last 20 sessions before test sessions were initiated. Birds earned 61% to 71% of their reinforcers for responding on the pentobarbital-biased key after pentobarbital and 67% to 69% of their reinforcers for responding on the saline-biased key after saline administration during these training sessions. Birds made 61% to 79% of their responses on the pentobarbital-biased key after pentobarbital and allocated 66% to 79% of their time to responding on that key. The birds made 54% to 86% of their responses on the saline-biased key after saline and spent 62% to 73% of their time responding on that key. Some birds slightly undermatched the ratio of responses to the ratio of reinforcers delivered following pentobarbital (P347) or saline (P257 and P260), whereas other birds

Table 1

Individual-subject and group means of 10 pentobarbital training sessions and 10 saline training sessions under the concurrent FI 100-s FI 200-s schedule for responding, reinforcers delivered and time allocated to responding on the pentobarbital-biased key, and the number of CODs.

	Pentobarbital training sessions									
	Responses			Reinforcers			Time (seconds)			
Bird	Pent	Sal	%Pent	Pent	Sal	%Pent	Pent	Sal	%Pent	CODs
P347	1,328	732	65	19	8	71	1,817	470	79	109
P257	1,706	447	79	22	10	68	1,543	694	69	52
P259	1,071	685	61	12	7	61	1,668	659	72	75
P260	1,546	508	75	21	12	64	1,502	766	66	70
M	1,413	593	70	19	9	66	1,633	647	72	77

overmatched the ratio of responses to the ratio of reinforcers delivered. Bird P259 perfectly matched the percentage of responses on the pentobarbital-biased key to the percentage of reinforcers delivered for responses on that key. On average, the ratio of responses on the key programmed to deliver responses under the shorter FI component and the ratio of time spent responding on that key were close to the ratio of reinforcers delivered for responding on each key (after pentobarbital, 66% of reinforcers, 70% of responses, and 72% of time allocation were associated with the pentobarbital-biased key; after saline, 68% of reinforcers, 70% of responses, and 68% of time allocation were associated with the saline-biased key). These values are close to perfect matching (Baum, 1979). The mean number of CODs was higher after saline administration than after pentobarbital administration, but this effect was not consistent across birds. During training sessions, Birds P259 and P260 responded at higher overall rates after saline than after pentobarbital, whereas the other 2 birds responded at similar rates after saline and pentobarbital (Table 1).

Figure 1 shows cumulative response records for Bird P347 for performance under the concurrent FI 100-s FI 200-s schedule. Performance during training sessions is shown in the left column. During training sessions with both saline and pentobarbital, responding under the FI 100-s component of the schedule was characterized by a postreinforcement pause, followed by a short period of accelerated responding to a terminal rate that was maintained until delivery of the reinforcer. Under the FI 200-s component, responding was characterized by long pauses followed by bursts of responding. These bursts usually occurred during the postreinforcement pause in responding on the other key, especially after saline administration. Although the response bursts on the key on which reinforcer delivery was programmed under the FI 200-s component usually occurred during the postreinforcement pause on the other key, responses under the FI 200-s component also occurred at other times to cause occasional interruptions in reponding on the key programmed under the FI 100-s component of the schedule, especially for pentobarbital training sessions. Other pigeons produced similar patterns of responding.

Table 2 shows stable data under the concurrent FI 40-s FI 80-s schedule for each bird. Birds earned 66% to 68% of their reinforcers both for responding on the pentobarbital-biased key after pentobarbital administration and for responding on the saline-biased key after saline administration. Birds made 60% to 85% of their responses on the pentobarbital-biased key after pentobarbital and allocated 57% to 70% of their time to responding on that key. The pigeons made 43% to 75% of their responses on the saline-biased key after saline and allocated 41% to 57% of their time to responding on that key. After pentobarbital administration, small amounts of both undermatching and overmatching of the ratio of responses to reinforcers delivered were observed in individual birds; however, after saline administration undermatching occurred for Birds P380, P260 (for both responses and time allocation), and P257 (for time allocation). The number of CODs was

Table 1
(*Extended*)

Saline training sessions									
Responses			Reinforcers			Time (seconds)			
Pent	Sal	%Sal	Pent	Sal	%Sal	Pent	Sal	%Sal	CODs
265	1,774	86	11	22	67	618	1,649	73	56
862	1,447	63	10	21	68	629	1,637	72	113
481	1,765	78	10	21	69	831	1,542	66	50
1,360	1,613	54	11	22	67	850	1,412	62	161
742	1,650	70	11	22	68	732	1,560	68	95

very similar after saline and the training dose of pentobarbital. During training sessions, all birds responded at higher overall rates after saline than after pentobarbital.

Figure 2 shows cumulative response records for Bird P347 under the concurrent FI 40-s FI 80-s schedule. During training sessions after administration of both saline and pentobarbital, responding under the FI 40-s component of the concurrent FI 40-s FI 80-s

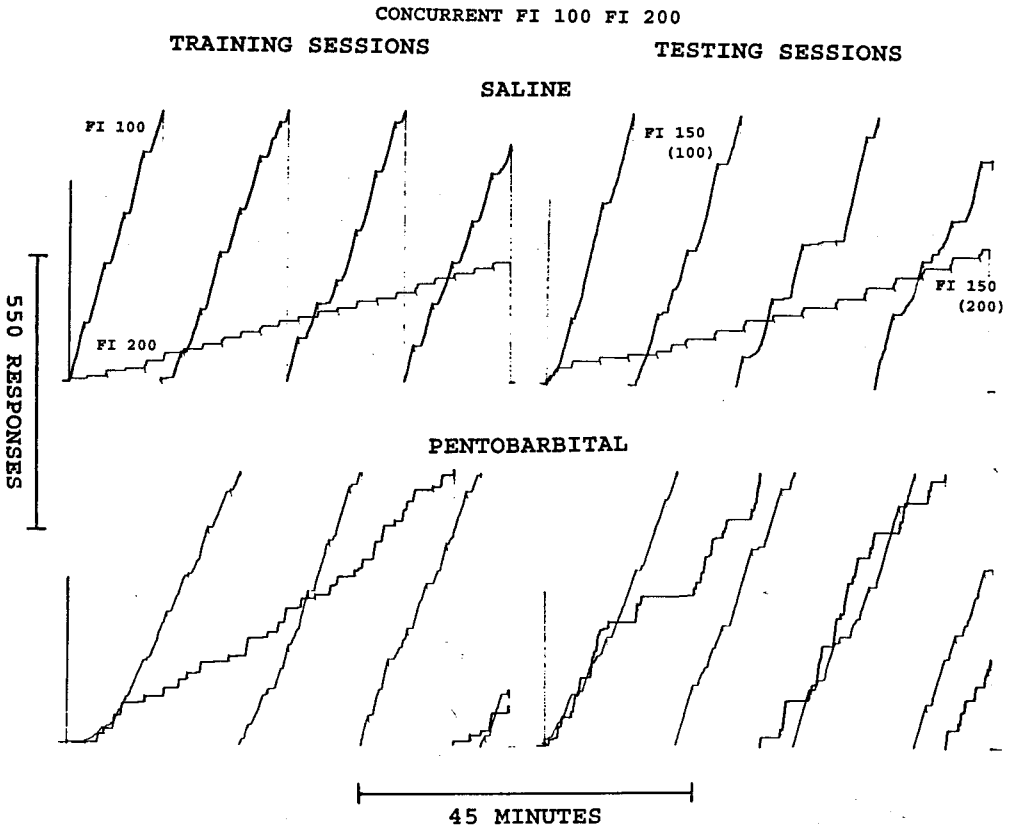

Fig. 1. Cumulative response records under the concurrent FI 100-s FI 200-s schedule for Bird P347 during training sessions (left column) and test sessions (second column) after saline (top row) or 5.0 mg/kg pentobarbital (bottom row) administration. Downward deflections of the response pen represent reinforcer delivery. The cumulative records have been overlaid to permit comparisons of patterns of responding on the two keys.

Table 2

Individual-subject and group means of 10 pentobarbital training sessions and 10 saline training sessions under the concurrent FI 40-s FI 80-s schedule for responding, reinforcers delivered and time allocated to responding on the pentobarbital-biased key, and the number of CODs.

	Pentobarbital training sessions									
	Responses			Reinforcers			Time (seconds)			
Bird	Pent	Sal	%Pent	Pent	Sal	%Pent	Pent	Sal	%Pent	CODs
P347	1,830	327	85	42	20	68	1,129	478	70	75
P257	900	600	60	42	20	68	951	657	59	82
P380	1,874	608	75	41	21	66	932	674	58	123
P260	1,027	229	81	41	20	67	915	694	57	75
M	1,408	441	75	42	20	67	982	626	61	89

schedule was characterized by a postreinforcement pause, followed by a short period of accelerated responding to a terminal rate that was maintained until delivery of the reinforcer. Under the FI 80-s component, responding was characterized by longer pauses followed by bursts of responding. These bursts usually occurred during the postreinforcement pause in responding on the other key after both saline and pentobarbital administration. Similar patterns of responding were observed in other pigeons.

Figure 3 shows the dose–response curve for the effects of pentobarbital during test sessions. Points at C, which represent mean percentages of responding when the reinforcement schedule was changed from concurrent FI 100 s FI 200 s to FI 150 s FI 150 s, or concurrent FI 40 s FI 80 s to FI 60 s FI 60 s for these test sessions, show that these schedule changes did not disrupt control by the training dose of pentobarbital. This observation is confirmed by the cumulative response records shown in Figures 1 and 2, in which the patterns of responding are shown for Bird P347 when the schedule was changed from concurrent FI 100 s FI 200 s to concurrent FI 150 s FI 150 s (Figure 1) or from concurrent FI 40 s FI 80 s to concurrent FI 60 s FI 60 s (Figure 2). Patterns of responding under the FI 100-s component now changed to FI 150 s continued to show a typical FI pattern of responding (pause followed by acceleration to a high terminal rate of responding), except that the terminal rate of responding lasted longer due to the lengthening of the schedule component. Under the FI 200-s component, now also changed to FI 150 s, patterns of responding were similar to those during training sessions (long pauses followed by bursts of responding that often occurred during the postreinforcement pause on the other key). The rates of responding for Bird P347 were considerably higher after pentobarbital under the schedule component on which responses were reinforced under the FI 150-s schedule used during testing after having been reinforced under the FI 200-s component during training sessions (Figure 1); however, this effect was not observed consistently for Bird P347 or for the other birds.

When the pentobarbital dose–response curve was determined, low doses of pentobarbital produced responding on the pentobarbital-biased key at percentages close to those seen during saline training sessions (Figure 3). Increasing doses of pentobarbital produced an increased percentage of responding on the pentobarbital-biased key under both schedules. At the higher doses of pentobarbital, there was a tendency for the dose–response curve to turn over and begin to descend for Bird P260 under both schedules and perhaps also for Bird P380 under the concurrent FI 60-s FI 60-s schedule after training under concurrent FI 40 s FI 80 s.

Figure 4 shows dose–response curves for pentobarbital for the percentage of time allocated to responding on the pentobarbital-biased key under each schedule. When the birds were trained under the concurrent FI 100-s FI 200-s schedule and tested under the concurrent FI 150-s FI 150-s schedule, the time-allocation data were similar to the data for percentage of responses on the pentobarbital-biased key. That is, the percentage of time spent responding on the pentobarbital-

Table 2
(*Extended*)

Saline training sessions									
Responses			Reinforcers			Time (seconds)			
Pent	Sal	%Sal	Pent	Sal	%Sal	Pent	Sal	%Sal	CODs
298	867	75	21	41	66	698	910	57	71
400	586	59	20	40	67	890	730	45	81
931	744	45	19	41	68	908	709	44	160
452	344	43	19	41	67	951	664	41	80
520	635	55	20	41	67	861	753	47	98

biased key increased with dose, except for Bird P260, for which the curve turned over after the highest dose of pentobarbital. However, when the birds were trained under the concurrent FI 40-s FI 80-s schedule and tested under the concurrent FI 60-s FI 60-s schedule, the percentage of time spent on the two schedule components became less different from each other than occurred with the percentage of responses. This similarity in percentage of time spent responding on each schedule component when the schedule was

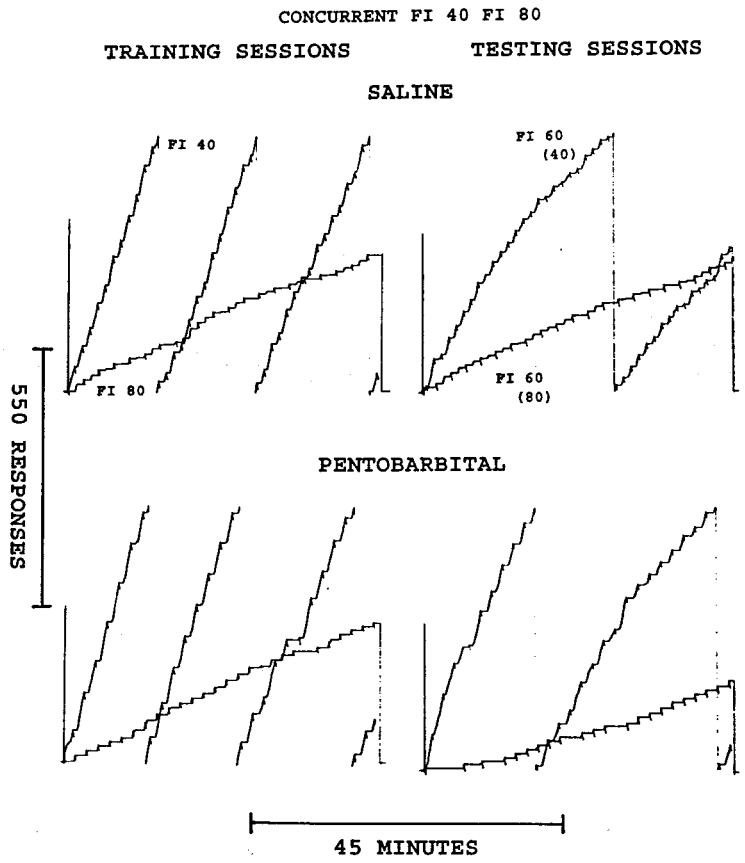

Fig. 2. Cumulative response records under the concurrent FI 40-s FI 80-s schedule for Bird P347. The details are as in Figure 1.

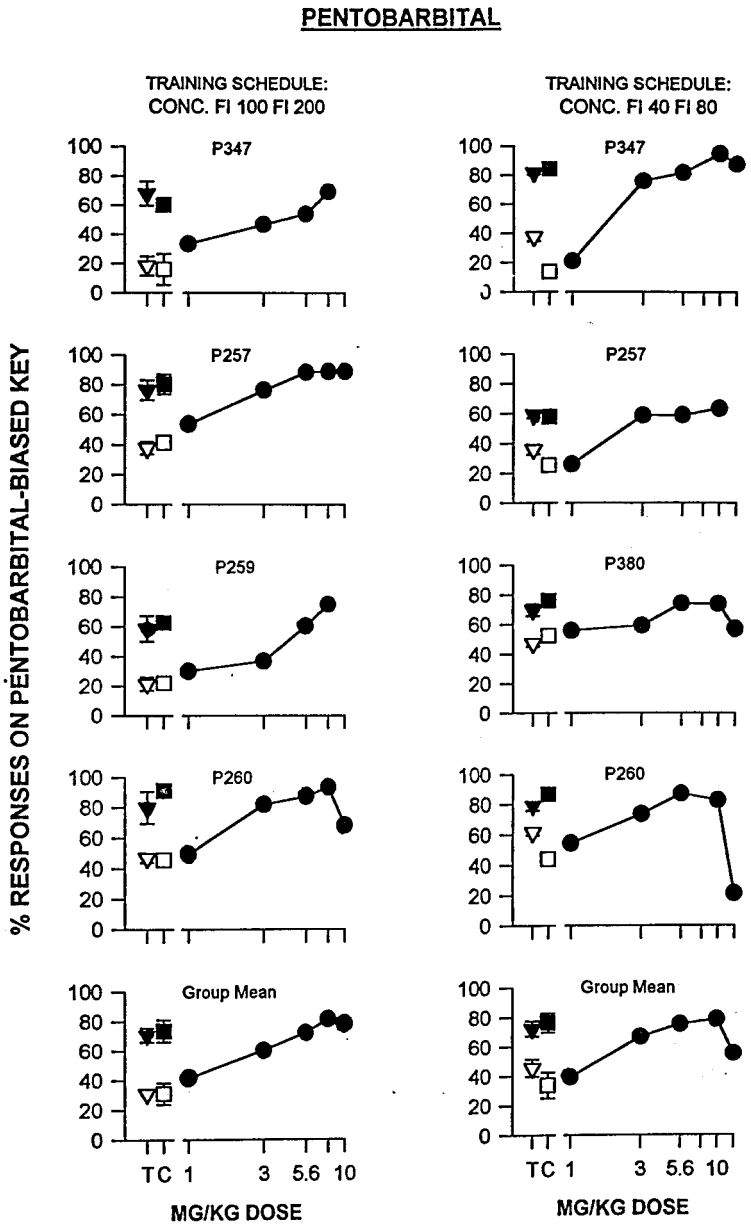

Fig. 3. Dose–response curves for the effects of pentobarbital on the percentage of responses on the pentobarbital-biased key on which, during training sessions, responses were reinforced under the FI 100-s component of the concurrent FI 100-s FI 200-s schedule (first column) and the FI 40-s component of the concurrent FI 40-s FI 80-s schedule (second column). Brackets at T (training sessions) show ±1 standard deviation around the mean based on the data obtained during training sessions. Brackets at C (control sessions for schedule changes) show ±1 standard deviation around the mean based on the control sessions in which the schedule was changed to concurrent FI 150 s FI 150 s (first column) or to concurrent FI 60 s FI 60 s (second column), which were the schedules used during determination of the dose–response curves. The filled circles show the pentobarbital dose–response curve with single observations made at each dose level. The filled triangles and squares above T and C show the effects of 5.0 mg/kg pentobarbital and saline during training and control sessions. The open triangles and squares above T and C show the effects of saline injections during training and control sessions.

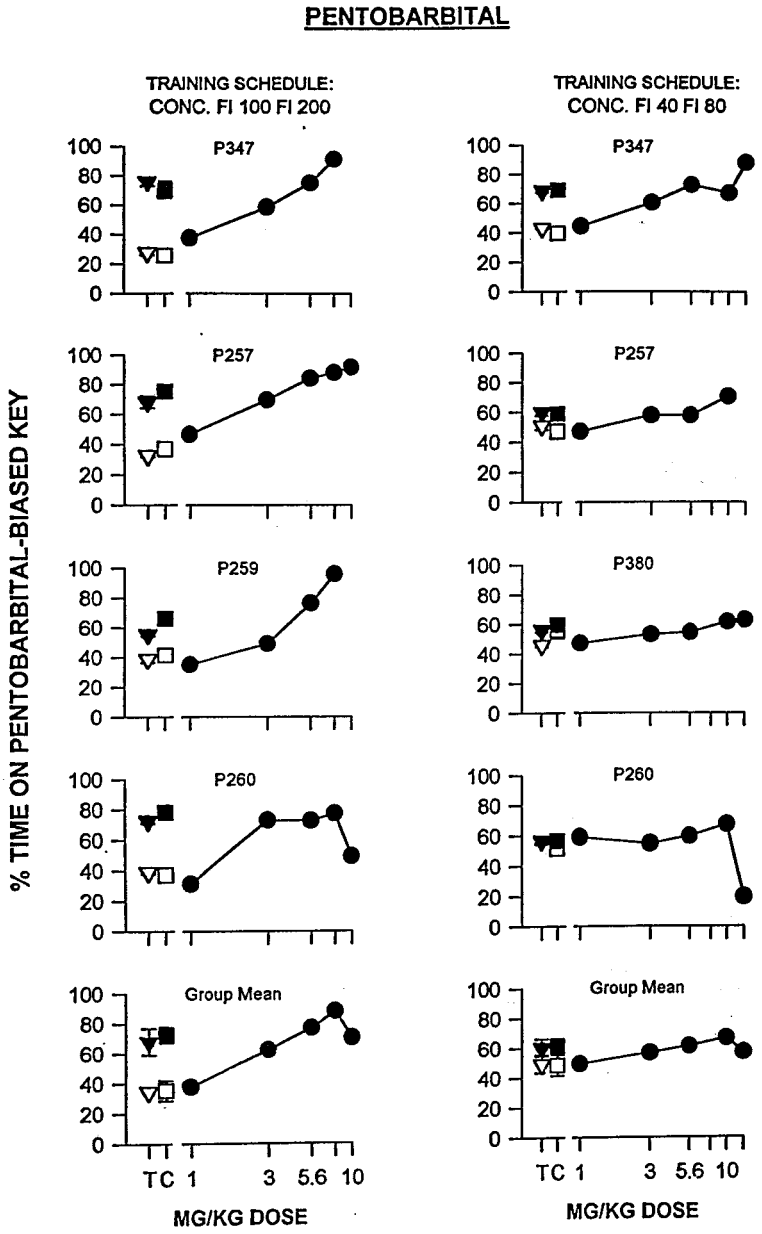

Fig. 4. The dose–response curve for the effects of pentobarbital on the percentage of time spent responding on the pentobarbital-biased key. Details as in Figure 3.

changed to concurrent FI 60 s FI 60 s and saline or the training dose of pentobarbital was administered caused the pentobarbital dose–response curve to be much flatter for time-allocation percentages than had occurred for the percentage of responses on the pentobarbital-biased key. Nevertheless, most birds showed a gradually increasing percentage of time spent responding on the pentobarbital-biased key as the dose of pentobarbital increased, except that again the dose–response curve descended for Bird P260 after the highest dose of pentobarbital. The raw data on which Figures 3 and 4 are based are shown in Appendixes A and B.

Figure 5 shows dose–response curves for

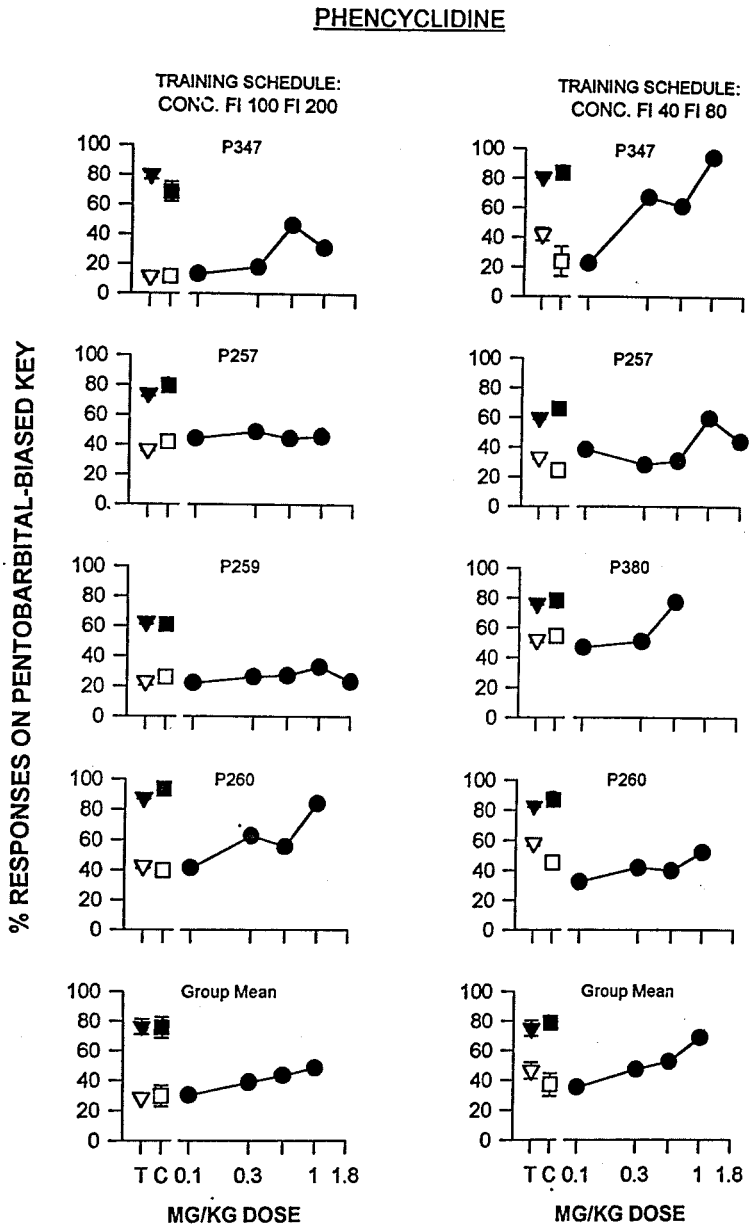

Fig. 5. The dose–response curve for the effects of phencyclidine on the percentage of responses on the pentobarbital-biased key. Details as in Figure 3.

the effects of phencyclidine on the percentage of responses on the pentobarbital-biased key under the two concurrent schedules. The effects of phencyclidine depended on the reinforcement schedule and the subject. In some instances, phencyclidine substituted fully for pentobarbital (P260 under concurrent FI 150 s FI 150 s; P347, P257, and P380 under concurrent FI 60 s FI 60 s), in other instances there was partial substitution (P347 under concurrent FI 150 s FI 150 s), and in other instances there was no substitution (P257 and P259 under concurrent FI 150 s FI 150 s; P260 under concurrent FI 60 s FI 60 s). There was no consistent pattern as to which birds or schedules showed full, partial, or no

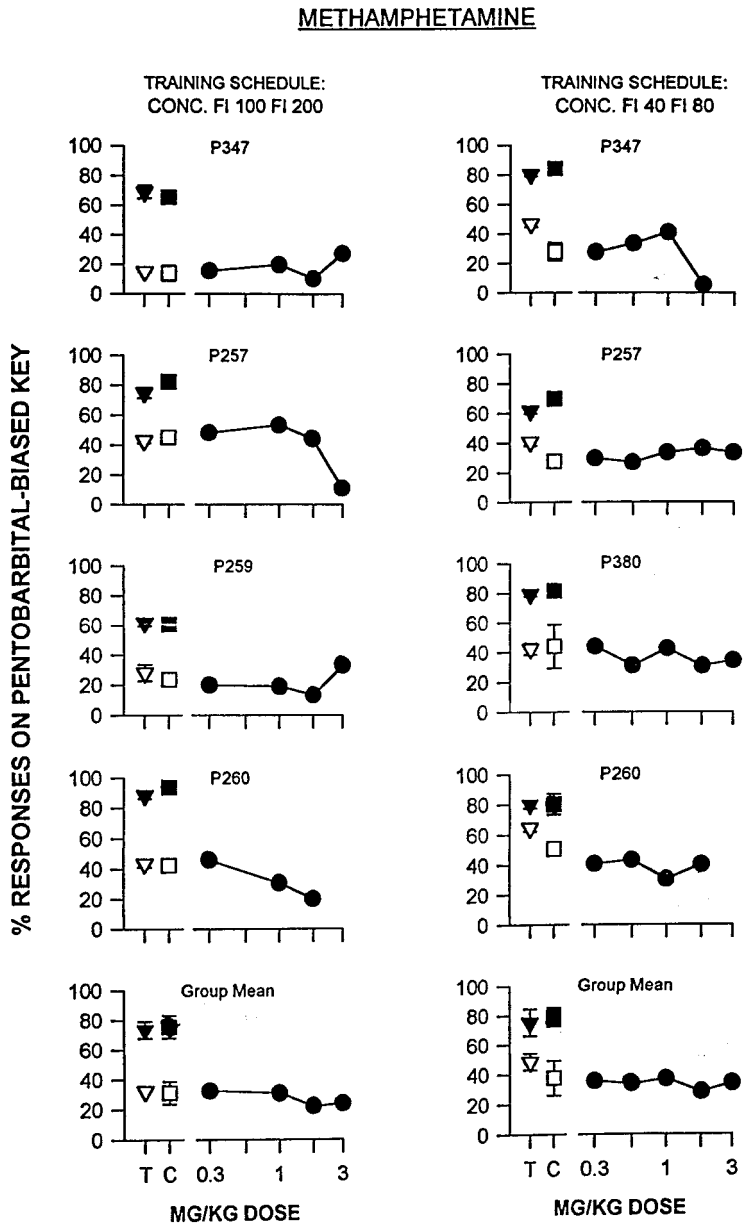

Fig. 6. The dose–response curve for the effects of methamphetamine on the percentage of responses on the pentobarbital-biased key. Details as in Figure 3.

substitution of phencyclidine for pentobarbital across reinforcement schedules.

Figure 6 shows the dose–response curves for the effects of methamphetamine on the percentage of responses on the pentobarbital-biased key under the two reinforcement schedules. Methamphetamine did not substitute for pentobarbital in any bird under either concurrent schedule. In a number of instances (P257 and P260 under concurrent FI 150 s FI 150 s and P347 and P260 under concurrent FI 60 s FI 60 s), responding on the pentobarbital-biased key fell below the level seen during saline training sessions after the administration of methamphetamine.

Figure 7 shows the dose–response curves

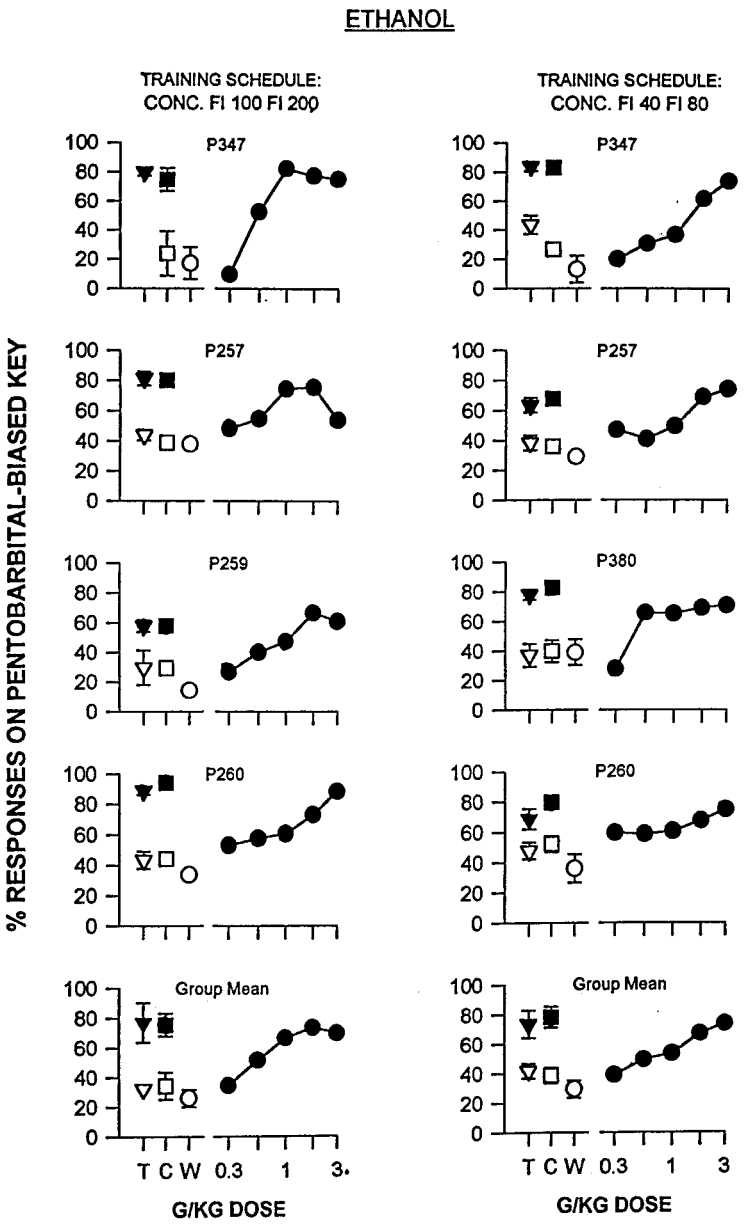

Fig. 7. The dose–response curve for the effects of ethanol on the percentage of responses on the pentobarbital-biased key. The abscissa is in grams per kilogram. Points above W show the effects of gavage with water. Other details as in Figure 3.

for substitution of ethanol for pentobarbital. Administration of water (points at W) produced responding on the saline-biased key. Increasing doses of ethanol increased responding on the pentobarbital-biased key, with full substitution occurring at doses of 1 to 3 g/kg. The dose–response curve turned over in Bird P257 under the concurrent FI 150-s FI 150-s schedule.

Figure 8 shows the dose–response curves for the substitution of chlordiazepoxide for pentobarbital. Increasing doses of chlordiazepoxide increased responding on the pentobarbital-biased key under both concurrent

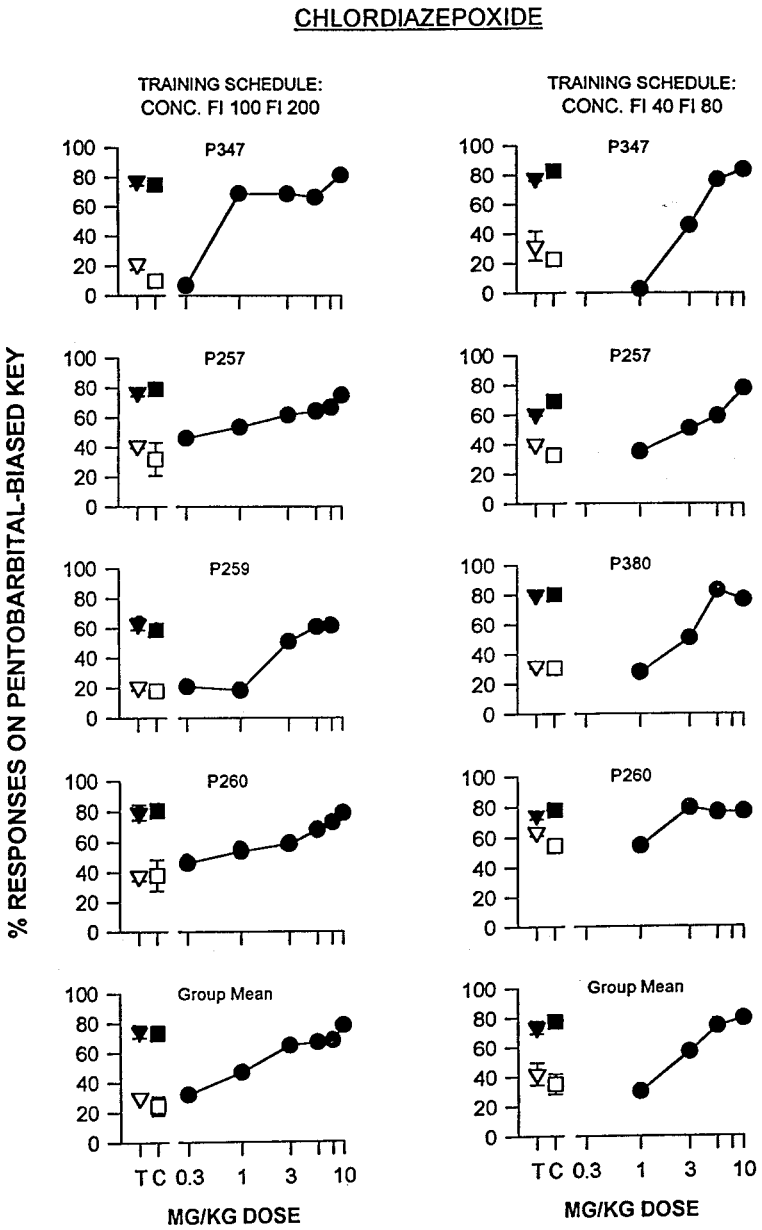

Fig. 8. The dose–response curve for the effects of chlordiazepoxide on the percentage of responses on the pentobarbital-biased key. Details as in Figure 3.

schedules. Full substitution of chlordiazepoxide for the training dose of pentobarbital occurred in all birds. The raw data on which Figures 5 through 8 are based are shown in Appendixes A and B.

Appendixes A and B also show the effects of these five drugs on the number of responses emitted, the time allocated to responding under each schedule component, and the total number of CODs for each pigeon during the substitution tests. The total number of responses emitted was decreased by higher doses of all drugs under both concurrent reinforcement schedules, demonstrating that the full dose–effect curve had been explored for these drugs. Changeover delays, a measure of

switching between keys, also usually decreased at high doses, although there were exceptions. The number of responses emitted and the number of CODs calculated across subjects for each drug were positively correlated (range, 0.44 to 0.81), except that the correlation between total responses and CODs was only 0.14 under the concurrent FI 100-s FI 200-s schedule after phencyclidine administration. These data suggest that at least some of the changes in CODs could be accounted for by decreases in overall rates of responding.

DISCUSSION

Although reinforcers were available only twice as frequently under the shorter FI component of each of these concurrent FI FI schedules, pigeons acquired the drug discrimination under both concurrent schedules. In the first experiment, pigeons learned to discriminate 5.0 mg/kg pentobarbital from saline under a concurrent FI 100-s FI 200-s schedule of food presentation. When responding stabilized, birds obtained about twice as many reinforcers under the FI 100-s component as under the FI 200-s component after both the training dose of pentobarbital and saline. Thus the actual ratio of reinforcers delivered was close to the programmed ratio under the concurrent FI 100-s FI 200-s schedule. Similar detection of small differences in reinforcement rate in the components of a concurrent VI VI schedule not involving drug discrimination have been reported previously (Charman & Davison, 1983).

In previous experiments using concurrent schedules of reinforcement, undermatching (a lower percentage of responses on the response alternative with the higher reinforcement rate than the percentage of reinforcers delivered for responses on that response alternative) is the rule (Davison & Nevin, 1999). Some degree of both undermatching and overmatching of responses and time-allocation ratios to reinforcer ratios occurred under the concurrent FI 100-s FI 200-s schedule in the present experiments, but the effects were usually small and were not consistent across birds or stimulus conditions. On average, the percentage of responses under the FI 100-s component of the concurrent schedule was close to the percentage of reinforcers delivered under that component. Thus, as a group the birds were close to matching responses to reinforcers delivered.

Under the concurrent FI 40-s FI 80-s schedule the pigeons also discriminated the presence or absence of 5.0 mg/kg of pentobarbital, with every bird earning almost exactly twice as many reinforcers under the FI 40-s component of the schedule as under the FI 80-s component. Thus, the ratio of reinforcers delivered under the two schedule components again was close to the ratio programmed by the reinforcement schedule. As in the concurrent FI 100-s FI 200-s schedule, some degree of both undermatching and overmatching occurred. In pentobarbital training sessions, some birds overmatched and some undermatched, but these effects were modest and depended on whether the measure of matching was responding or time allocation. In saline training sessions, 3 birds (Table 2) undermatched to a considerable extent on time allocation (P257) or on both time allocation and responding (P380 and P260).

The conditions under which undermatching occurs under concurrent reinforcement schedules in drug-discrimination experiments remain unclear. In our original experiments we used a concurrent FI 60-s FI 240-s schedule and found that pigeons usually matched response ratios and time-allocation ratios to reinforcer ratios after pentobarbital sessions, but that undermatching consistently occurred during saline training sessions (McMillan et al., 1997). More recently, pigeons trained to discriminate pentobarbital from saline were studied under a concurrent FI 15-s FI 285-s reinforcement schedule. Undermatching of response ratios and time-allocation ratios to reinforcer ratios was consistently observed for both saline and pentobarbital training sessions (McMillan & Li, 1999b). In experiments on concurrent schedules that did not involve drug discrimination, White and Davison (1973) studied a wide range of concurrent FI FI schedule values. They concluded that matching occurred under these schedules when typical FI patterns of responding occurred under both schedule components or neither schedule component. This result is different from ours, in which matching occurred despite differences in re-

sponse patterns under the FI components of the concurrent schedule. The data in Figures 1 and 2 for Bird P347 suggest that this pigeon did not exhibit consistent or pronounced undermatching, although the cumulative records show typical FI patterns of responding during the shorter FI components of the concurrent schedule and break-and-run responding during the longer FI components.

Under the present two concurrent schedules, the effects were similar when other doses and other drugs were substituted for the training dose of pentobarbital. Increasing doses of pentobarbital produced increased responding on the pentobarbital-biased key under both concurrent schedules. Occasionally, the pentobarbital dose–response curves descended after high doses. The inverted U-shaped dose–response curve occurred more frequently when the birds were studied under the concurrent FI 40-s FI 80-s schedule than under the FI 100-s FI 200-s schedule. As has been reported by others, phencyclidine produced a range of effects on responding under these schedules including no substitution, partial substitution, and full substitution for pentobarbital (McMillan, 1982; Snodgrass & McMillan, 1991). In contrast, methamphetamine did not substitute for pentobarbital, which is also consistent with other reports (McMillan & Li, 1999a; Witkin, Carter, & Dykstra, 1980). Other investigators have reported generalization from pentobarbital to chlordiazepoxide and ethanol (De Vry & Slangen, 1986; Grech & Balster, 1993; Jarbe & McMillan, 1983; Overton, 1966), which is also consistent with the findings of the present study. Thus, the substitution of other drugs for the training drug did not appear to be greatly influenced by the differences in concurrent-schedule values used in the present experiments.

In a number of instances, after the administration of methamphetamine the pigeons responded less often on the pentobarbital-biased key than they did after saline during training sessions. We have argued previously (Snodgrass & McMillan, 1996) that such responding may indicate a more salient stimulus of ''not pentobarbital'' than does saline, although other explanations such as an amphetamine-induced perseveration (Randrup & Munkvad, 1967) on one key are equally plausable. The opportunity to observe such effects may be an advantage of the use of concurrent schedules to study drug discrimination, because the procedures do not produce the floor and ceiling effects seen with most drug-discrimination procedures.

The data from the present experiments suggest that previous difficulties in studying drug discrimination in rats using concurrent reinforcement schedules (McMillan & Hardwick, 2000) may reflect a difference between rats and pigeons. In rats, a concurrent VI 40-s VI 80-s schedule maintained strong control over responding, but the training drug provided only weak control over responding when the drug-substitution tests were conducted under a concurrent VI 50-s VI 50-s schedule. When the training schedule was concurrent VI 60 s VI 240 s and drug-substitution tests were conducted under a concurrent VI 150-s VI 150-s schedule, stimulus control by the drug was improved. It was suggested that changes in shorter duration VI schedules might be more easily detected than changes in longer duration VI schedules. Therefore, schedule control might replace control by the drug stimulus more rapidly when short-duration VI schedules are manipulated than would occur with longer VI schedules. In the present experiments, there was no difference in stimulus control by the training drug under the two concurrent schedules despite a difference in the duration of the components of the two schedules. Unfortunately, the present experiments are far from conclusive on this point, because the present experiments used concurrent FI FI schedules with a ratio of 2:1 in the delivery of reinforcers under these FI components and the experiments with rats used concurrent VI VI schedules with a ratio of 4:1 in the delivery of reinforcers under the VI components. Thus, the differences between rats and pigeons may reflect differences between FI and VI schedules or differences between the ratios of reinforcer delivery under the reinforcement schedules that were studied.

As indicated previously, there is now a database suggesting that the maintenance of drug discrimination under interval schedules generates graded dose–response curves, whereas the maintenance of drug discrimination under ratio schedules generates quantal dose–response curves. The present experiments provide data both sup-

porting and not supporting this supposition. If the dose–response curves for pentobarbital, chlordiazepoxide, and ethanol (all drugs for which complete substitution occurred in most birds) are considered, the curves usually appear to be graded. Exceptions in which the curves are quantal occurred under concurrent FI 60 s FI 60 s after pentobarbital for P257 (Figure 3), after chlordiazepoxide for P260 (Figure 8), and perhaps after ethanol for P380 (Figure 7). Thus quantal dose–response curves occurred only two or three times out of a total of 24. However, in many instances in which the dose–response curve is graded, low doses produced responding on the saline-biased key after which a higher dose caused responding to shift to the pentobarbital-biased key without intermediate responding, despite the graded shape of the total dose–response curve. The problem with studying shapes of dose–response curves under concurrent schedules in which the ratio of reinforcer delivery under the two schedule components is only 2:1 is the compression of the dose–response curve. It is difficult to determine if responding is graded or quantal when the training schedules have compressed the difference between responding on the drug-biased key and responding on the saline-biased key to such a narrow range. The fact that graded dose effects are seen so frequently even under these conditions is strong evidence that interval schedules do favor the occurrence of graded responding.

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APPENDIX A

For each pigeon, under the concurrent FI 100-s FI 200-s schedule, the dose–response data for each drug are shown. The data are the number of changeover delays (CODs); the number of responses, reinforcers, and time (seconds) allocated to the pentobarbital (Pb) and saline (S) biased keys; and the percentage of responses and time emitted on the pentobarbital-biased key (%Pb).

			Responses			Reinforcers		Time		
Pigeon	Dose	CODs	Pb	S	% Pb	Pb	S	Pb	S	% Pb
Pentobarbital (mg/kg)										
P347	0.0	56	376	2,029	16	15	15	586	1,691	26
	1.0	72	1,079	2,163	33	16	15	854	1,416	38
	3.0	149	1,633	1,873	47	15	14	1,329	944	58
	5.6	159	1,530	1,316	54	14	12	1,714	571	75
	7.8	63	776	347	69	13	5	2,127	198	91
P257	0.0	174	1,202	1,699	41	15	15	839	1,434	37
	1.0	145	1,457	1,244	54	15	14	1,063	1,213	47
	3.0	68	2,131	654	77	16	14	1,585	690	70
	5.6	39	2,201	284	89	16	15	1,923	353	84
	7.8	32	1,789	217	89	14	12	2,025	268	88
	10.0	20	1,067	130	89	10	8	2,140	186	92
P259	0.0	33	276	1,018	22	14	9	958	1,349	42
	1.0	98	1,244	2,890	30	14	15	801	1,476	35
	3.0	63	881	1,500	37	13	11	1,130	1,170	49
	5.6	63	948	621	60	8	7	1,788	549	77
	7.8	13	215	72	75	8	7	2,291	92	96
P260	0.0	209	1,615	1,898	45	13	15	845	1,433	37
	1.0	157	1,446	1,480	49	13	15	714	1,565	31
	3.0	60	2,040	450	82	15	16	1,659	612	73
	5.6	34	1,395	205	87	15	16	1,650	622	73
	7.8	34	2,269	155	94	15	14	1,765	515	77
	10.0	65	1,415	654	68	10	13	1,135	1,169	49
Chlordiazepoxide (mg/kg)										
P347	0.0	42	201	1,926	10	14	14	661	1,627	29
	0.3	47	151	2,079	7	13	15	497	1,787	22
	1.0	78	1,398	634	69	15	14	1,180	1,098	52
	3.0	35	1,380	630	69	10	8	1,200	1,100	52
	5.6	46	616	312	66	10	8	1,414	939	60
	7.8									
	10.0	54	524	129	81	9	9	1,541	792	78
P257	0.0	123	817	1,211	32	14	14	833	1,471	36
	0.3	130	1,583	1,843	46	15	14	880	1,398	39
	1.0	105	1,809	1,561	54	14	15	1,124	1,174	49
	3.0	130	1,312	816	62	15	14	1,142	1,134	50
	5.6	78	1,372	762	64	12	13	1,228	1,068	53
	7.8	57	2,257	1,129	67	13	12	1,390	871	61
	10.0	110	2,790	938	75	16	15	1,526	743	67
P259	0.0	44	353	1,685	18	15	15	654	1,624	29
	0.3	30	246	942	21	15	10	747	1,550	33
	1.0	59	610	2,719	18	16	15	525	1,746	23
	3.0	53	1,675	1,620	51	15	16	1,317	998	57
	5.6	58	810	524	61	11	12	1,347	923	59
	7.8	63	860	534	62	9	11	1,670	634	72

APPENDIX A

(*Continued*)

			Responses			Reinforcers		Time		
Pigeon	Dose	CODs	Pb	S	% Pb	Pb	S	Pb	S	% Pb
P260	0.0	211	1,046	1,609	38	15	16	865	1,407	38
	0.3	219	1,413	1,663	46	15	16	905	1,359	40
	1.0	221	1,654	1,411	54	15	16	892	1,371	39
	3.0	66	1,235	869	59	15	14	1,332	977	58
	5.6	82	1,327	629	68	11	13	1,329	970	58
	7.8	109	1,571	591	73	12	11	1,389	897	61
	10.0	119	1,280	345	79	12	13	1,531	753	70
Ethanol (g/kg)										
P347	0.00	47	564	1,927	24	14	13	734	1,551	32
	0.30	33	99	935	10	10	8	474	1,851	20
	0.56	80	1,580	1,420	53	13	11	1,656	645	72
	1.00	38	2,391	511	82	15	14	1,767	513	78
	1.80	31	530	153	78	10	9	2,205	165	93
	3.00	30	444	146	75	9	8	2,103	259	89
P257	0.00	161	1,107	1,717	39	15	15	865	1,434	38
	0.30	132	1,430	1,519	48	15	15	850	1,421	37
	0.56	144	1,682	1,377	55	14	14	944	1,336	41
	1.00	113	2,100	711	75	13	12	1,322	970	58
	1.80	129	2,340	748	76	15	14	1,559	716	69
	3.00	43	567	670	46	8	9	1,876	477	80
P259	0.00	37	553	1,271	29	15	15	678	1,606	30
	0.30	45	643	1,759	27	13	15	789	1,486	35
	0.56	45	569	853	40	13	14	1,086	1,199	48
	1.00	24	265	293	47	7	8	1,699	638	73
	1.80	68	1,605	802	67	15	12	1,241	1,045	54
	3.00	62	1,023	651	61	11	12	1,166	1,138	51
P260	0.00	241	1,108	1,388	44	16	15	815	1,453	36
	0.30	243	2,236	1,970	53	14	15	1,023	1,241	45
	0.56	280	2,224	1,636	58	15	14	1,092	1,176	48
	1.00	263	2,267	1,471	61	15	16	1,062	1,190	47
	1.80	118	2,187	811	73	16	15	1,394	874	61
	3.00	66	3,114	417	88	14	15	1,621	658	71
Methamphetamine (mg/kg)										
P347	0.0	60	338	2,163	14	16	15	726	1,547	32
	0.3	58	447	2,425	16	16	15	734	1,537	32
	1.0	84	489	1,981	20	16	15	893	1,376	39
	1.8	40	220	1,879	10	16	15	672	1,600	30
	3.0	96	739	1,947	28	16	15	835	1,434	37
P257	0.0	164	1,410	1,736	45	15	15	972	1,302	43
	0.3	153	1,317	1,406	48	15	15	1,163	1,108	51
	1.0	170	1,259	1,103	53	15	14	1,190	1,084	52
	1.8	105	515	649	44	12	14	814	1,476	36
	3.0	61	270	2,154	11	8	10	417	1,908	18
P259	0.0	51	502	1,705	24	14	16	657	1,623	29
	0.3	62	548	2,200	20	14	16	681	1,593	30
	1.0	93	668	2,841	19	15	16	485	1,785	21
	1.8	32	194	1,261	13	10	13	251	2,053	11
	3.0	67	850	1,736	33	13	14	809	1,479	35
P260	0.0	183	1,102	1,503	42	15	16	738	1,531	33
	0.3	156	1,274	1,511	32	15	16	664	1,603	29
	1.0	40	75	170	31	12	2	192	2,148	8
	1.8	9	25	100	20	11	1	49	2,301	2
Phencyclidine (mg/kg)										
P347	0.0	51	266	2,061	12	15	15	697	1,578	31
	0.1	38	329	2,181	13	16	15	653	1,619	29

APPENDIX A

(*Continued*)

			Responses			Reinforcers		Time		
Pigeon	Dose	CODs	Pb	S	% Pb	Pb	S	Pb	S	% Pb
	0.3	42	505	2,612	18	14	14	706	1,576	31
	0.56	52	1,292	1,558	46	15	13	1,195	1,090	52
	1.0	80	657	1,472	31	13	12	1,138	1,159	50
P257	0.0	115	1,264	1,779	42	14	15	809	1,468	36
	0.1	126	1,446	1,826	44	15	15	881	1,395	39
	0.3	93	1,789	1,849	49	15	14	814	1,460	36
	0.56	61	1,239	1,542	44	13	13	927	1,363	41
	1.0	62	1,257	1,495	46	14	14	1,113	1,171	49
P259	0.0	44	404	1,287	26	12	15	856	1,442	37
	0.1	36	436	1,544	22	14	14	981	1,303	43
	0.3	42	543	1,509	26	13	15	838	1,451	37
	0.56	42	841	2,240	27	12	14	823	1,470	36
	1.0	52	983	2,057	33	11	14	682	1,611	30
P260	0.0	157	1,117	1,523	40	15	16	793	1,478	35
	0.1	49	1,319	1,692	41	15	15	751	1,518	33
	0.3	109	2,735	1,647	63	15	15	1,285	994	56
	0.56	90	1,905	1,443	56	14	13	1,114	1,162	49
	1.0	30	934	184	84	14	9	2,127	206	91

APPENDIX B

For each pigeon, under the concurrent FI 40-s FI 80-s schedule, the dose–response data for each drug are shown. The data are the number of changeover delays (CODs); the number of responses, reinforcers, and time (seconds) allocated to the pentobarbital (Pb) and saline (S) biased keys; and the percentage of responses and time emitted on the pentobarbital-biased key (%Pb).

			Responses			Reinforcers		Time		
Pigeon	Dose	CODs	Pb	S	% Pb	Pb	S	Pb	S	% Pb
Pentobarbital (mg/kg)										
P347	0.0	55	207	1,288	14	24	32	748	1,121	39
	1.0	68	470	1,749	21	27	24	937	1,176	44
	3.0	56	1,440	450	76	28	23	963	626	61
	5.6	56	1,561	346	82	26	24	1,160	434	73
	10.0	24	1,305	67	95	17	2	1,156	568	67
	13.0	35	1,621	222	88	23	24	1,457	191	88
P257	0.0	66	301	880	25	26	27	862	980	47
	1.0	54	325	925	26	27	27	743	835	47
	3.0	70	940	666	59	26	25	919	671	58
	5.6	62	857	601	59	28	26	911	666	58
	10.0	41	529	301	64	25	18	1,147	478	71
P380	0.0	131	824	740	52	27	28	879	707	56
	1.0	192	1,348	1,072	55	27	28	744	834	47
	3.0	183	1,331	918	59	26	28	837	743	53
	5.6	99	2,036	710	74	27	28	853	718	54
	10.0	65	2,021	722	74	27	27	971	606	62
	13.0	79	2,087	1,559	57	27	28	993	583	63
P260	0.0	59	301	384	44	26	28	811	767	51
	1.0	56	500	418	54	26	28	931	647	59
	3.0	57	1,429	280	74	27	26	866	715	55
	5.6	50	1,280	189	87	27	24	968	652	60
	10.0	34	1,337	278	83	22	14	1,114	538	67
	13.0	51	345	1,282	21	11	22	329	1,335	20

APPENDIX B

(*Continued*)

Pigeon	Dose	CODs	Responses			Reinforcers		Time		
			Pb	S	% Pb	Pb	S	Pb	S	% Pb
Chlordiazepoxide (mg/kg)										
P347	0.0	61	331	1,124	23	28	27	781	793	49
	1.0	17	31	1,234	2	3	27	160	1,515	10
	3.0	73	1,032	1,225	46	25	25	790	803	50
	5.6	58	993	294	77	19	18	1,274	377	77
	10.0	1	16	3	84	2	0	1,789	3	100
P257	0.0	62	415	855	33	26	27	756	830	48
	1.0	55	469	867	35	26	27	694	889	44
	3.0	59	639	622	51	23	24	645	960	40
	5.6	66	569	391	59	22	22	943	674	58
	10.0	75	1,501	421	78	23	25	993	570	64
P380	0.0	57	305	691	30	26	28	670	908	42
	1.0	57	297	768	28	27	28	624	950	40
	3.0	62	640	618	51	27	28	777	797	49
	5.6	66	1,583	326	83	27	28	979	593	62
	10.0	69	1,428	426	77	26	26	899	686	57
P260	0.0	54	545	454	54	27	28	848	727	54
	1.0	55	706	590	54	25	27	866	719	55
	3.0	53	1,225	318	79	27	27	832	745	53
	5.6	56	1,051	324	76	27	27	890	688	56
	10.0	59	1,187	357	77	27	26	941	642	59
Ethanol (g/kg)										
P347	0.00	52	171	1,038	13	20	27	562	1,051	35
	0.30	52	217	846	20	26	27	772	810	49
	0.56	83	630	1,419	31	28	27	831	749	53
	1.00	63	537	918	37	25	26	812	778	51
	1.80	88	1,294	797	62	22	26	940	673	58
	3.00	14	230	80	74	14	7	1,319	410	76
P257	0.00	70	382	932	29	28	27	700	885	43
	0.30	61	688	767	47	27	27	767	811	49
	0.56	89	687	979	41	26	27	771	824	48
	1.00	60	612	620	50	23	21	806	816	50
	1.80	55	1,003	450	69	21	20	1,093	680	62
	3.00	22	514	177	74	14	8	1,407	305	82
P380	0.00	76	462	673	39	27	28	775	799	44
	0.30	53	294	762	28	26	28	617	961	39
	0.56	38	961	500	66	27	16	1,091	532	67
	1.00	68	483	257	65	27	28	880	696	56
	1.80	55	970	431	69	28	20	806	795	50
	3.00	72	1,088	448	71	26	18	824	796	51
P260	0.00	93	437	847	36	26	28	730	856	46
	0.30	70	723	489	60	26	27	977	603	61
	0.56	112	1,095	771	59	26	27	773	805	49
	1.00	102	886	572	61	26	25	903	685	57
	1.80	116	1,269	606	68	26	27	844	741	53
	3.00	64	852	284	75	27	27	920	657	58
Methamphetamine (mg/kg)										
P347	0.0	60	354	495	28	28	27	761	814	48
	0.3	62	409	1,070	28	27	27	809	765	51
	0.56	75	475	941	34	28	27	868	705	55
	1.0	83	710	1,018	41	26	26	723	878	45
	1.8	28	78	1,323	6	6	26	115	1,549	7
P257	0.0	60	341	886	28	26	27	736	850	46
	0.3	56	313	743	30	27	27	803	775	51
	0.56	57	331	902	27	25	27	665	921	42

APPENDIX B

(*Continued*)

			Responses			Reinforcers		Time		
Pigeon	Dose	CODs	Pb	S	% Pb	Pb	S	Pb	S	% Pb
	1.0	58	417	820	34	28	27	738	847	46
	1.8	91	536	937	36	25	27	561	1,023	35
	3.0	85	324	638	34	19	20	751	887	46
P380	0.0	89	658	730	44	26	28	825	757	52
	0.3	57	385	492	44	27	28	865	707	55
	0.56	60	298	656	31	27	28	818	759	52
	1.0	75	609	829	42	26	28	531	1,046	34
	1.8	56	275	618	31	26	28	614	964	39
	3.0	50	233	446	34	25	28	657	926	42
P260	0.0	55	411	395	51	27	28	869	706	55
	0.3	58	386	558	41	27	28	737	837	47
	0.56	75	586	768	43	26	28	704	880	44
	1.0	15	101	230	31	17	8	1,255	442	74
	1.8	58	315	467	40	18	15	1,004	658	60
Phencyclidine (mg/kg)										
P347	0.0	51	296	1,006	24	25	27	476	1,031	31
	0.1	54	367	1,238	23	27	27	639	936	41
	0.3	54	1,711	821	68	27	23	999	596	63
	0.56	68	1,389	868	62	27	26	901	684	57
	1.0	32	1,183	65	95	27	5	1,569	102	94
P257	0.0	59	283	870	24	27	27	501	855	35
	0.1	72	520	834	38	27	25	756	824	48
	0.3	66	434	1,097	28	28	27	603	790	43
	0.56	52	389	869	31	27	27	712	866	45
	1.0	56	722	487	60	24	25	860	740	54
	1.8	49	512	643	44	23	24	808	797	50
P380	0.0	86	834	685	54	27	28	794	653	54
	0.1	57	475	540	47	27	28	816	758	52
	0.3	59	490	475	51	27	27	810	725	53
	0.56	104	2,125	620	77	26	26	1,058	531	67
P260	0.0	54	324	391	45	27	28	555	577	47
	0.1	54	196	410	32	26	28	780	797	49
	0.3	63	462	639	42	25	28	766	819	48
	0.56	145	853	1,275	40	24	25	708	908	44
	1.0	93	1,588	1,459	52	26	24	852	743	53